

Improvement of QR Code Recognition Based on Pillbox Filter Analysis

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Abstract

The objective of this paper is to perform the innovation design for improving the recognition of a captured QR code image with blur through the Pillbox filter analysis. QR code images can be captured by digital video cameras. Many factors contribute to QR code decoding failure, such as the low quality of the image. Focus is an important factor that affects the quality of the image. This study discusses the out-of-focus QR code image and aims to improve the recognition of the contents in the QR code image. Many studies have used the pillbox filter (circular averaging filter) method to simulate an out-of-focus image. This method is also used in this investigation to improve the recognition of a captured QR code image. A blurred QR code image is separated into nine levels. In the experiment, four different quantitative approaches are used to reconstruct and decode an out-of-focus QR code image. These nine reconstructed QR code images using methods are then compared. The final experimental results indicate improvements in identification.

Keywords: QR code, pillbox filter, recognition

1. Introduction

In the recognition of the QR code, the information stored within the QR code can be easily retrieved by a decoding process that utilizes an image-capturing device with at least 300,000 pixels combined with the application of decoding software. The decoding is also not restrained by the angle of the image because the captured image can be rotated to the correct angle before performing the decoding. Given this flexibility, the QR code can be widely used in various trades and fields [1-3]. The QR code has 40 versions, from No.1 to No. 40. The higher the version number, the more data it stores and the larger the size of the image. Using the same equipment to obtain a version with a higher number under the same environmental conditions, the results will be happened in an out-of-focus image. Before decoding the QR code, the coded image should be first obtained. The quality of the image determines the success rate of the decoding; factors that influence image quality include the characteristics of the image-capturing device [4], the characteristics of the media containing the QR code, and out-of-focus blurriness due to the distance to the QR code image [5-8].

Although an out-of-focus QR code image is one of the main factors contributing to decoding failure, very few investigations on decoding out-of-focus QR code images have been conducted. The aim of this paper is to investigate into the characteristics of out-of-focus blurry QR code images. Four reconstruction methods are proposed to reconstruct nine new QR code simulations that have different degrees of blurriness. To find a reconstruction method with the best recognition ability, the discrepancies between the original QR code image and reconstructed QR code image were investigated to check whether decoding can be conducted [9-12].

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The hypothesis of this paper is based on whether the positions on the QR code can be fully determined and the diagram is absolutely clear and correct. Nine out-of-focus QR code images with different degrees of blurriness are reconstructed using the following methods to obtain a clear QR code: average reconstruction, center-point reconstruction, adjacent pixel reference, and adjacent pixel-center-point reference. The obtained QR codes are then compared against the original QR code. The pillbox filter method is used to simulate blurry images, which are then applied to the QR code image. The pillbox method, which is used to conduct distorting simulation of the QR code image, not only creates an out-of-focus blurry phenomenon visually but also simulates out-of-focus situations, as shown by many imaging-related studies. Therefore, this study also used the pillbox filter to simulate out-of-focus situations. Using different degrees of blurriness and different reconstruction methods, the change in the interpreted values of the QR code are analyzed to find a better recognition method. This study primarily investigates out-of-focus QR code images and proposes four types of reconstruction methods for finding a high-performance recognition reconstruction algorithm.

2. QR Code Property

A complete QR code assembly includes an encoding region and function patterns. The encoding region is used to store data, and the function patterns are used to determine the alignment of the QR code. Function patterns include position detection patterns, separators for position detection patterns, timing patterns, and alignment patterns. A two-dimensional array is used to represent the QR code dot matrix. The boundaries for the size $n \times n$ array is (0 to $(n-1)$, 0 to $(n-1)$). The binary value 1 denotes the totally black module, and 0 denotes the totally white module. The QR Size denotes the number of modules in the horizontal and vertical axes of the QR code. Fig. 1 shows the structure of a normal QR code pattern.

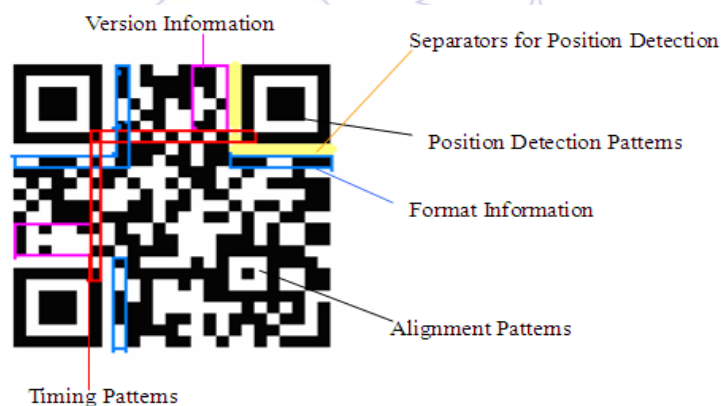


Fig. 1 QR code structure

Position detection patterns are used to define the boundary of the entire QR code on the entire diagram. Each individual QR code has three positioning symbols that are incorporated into the QR code during the initial encoding and are individually distributed on the top left, bottom left, and top right of the QR code boundary. The separators for the position detection patterns are used to divide the positioning symbol and data symbol regions with widths of 1- to 0-bit and positioned individually at three locations: top left, top right, and bottom left. Timing patterns are used to determine the version information, as well as the alignment and density of the bit coordinates. Alignment patterns are used to reconstruct the corresponding bit coordinates of the concurrent image, thereby reducing the influences caused by the distorted image. The encoding region contains the data and QR Code formatting information, version information and the data, and error correction keys. The format information stores the QR code error correction level and applies encoded masking information and is a symbol required by the QR code decoding. The version information stores the QR code-encoded version information. The QR code must meet the encoded versions 7 to 40. Data and error correction code words store the encoded version information and calculated error correction key. The calculation

of error correction code uses the Bose-Chaudhuri-Hocquenghem(BCH) code. It uses 5 bits on behalf of the version number. And it also uses 10 bits to present the version information of error correction code. Here, it will be used the form as BCH(15,5).

The format of the information to the left 5 bits displacement 10 bit divides by $G(x) = x^{15} + x^{10} + x^5 + x + 1$. The result of 10 bits remainder is the error correction code bits. The error correction level indicators are shown in Table 1.

Table 1 Error correction level indicators

Error correction level	Indication bits encoded value	Number of error corrections (%)
L	01	7
M	00	15
Q	11	25
H	10	30

2.1. Encoding the QR code [13]

The QR code encoding process includes the inputting of the encoded data up to the generation of the QR code diagram. Fig. 2 shows the procedure for the standard QR code encoding.

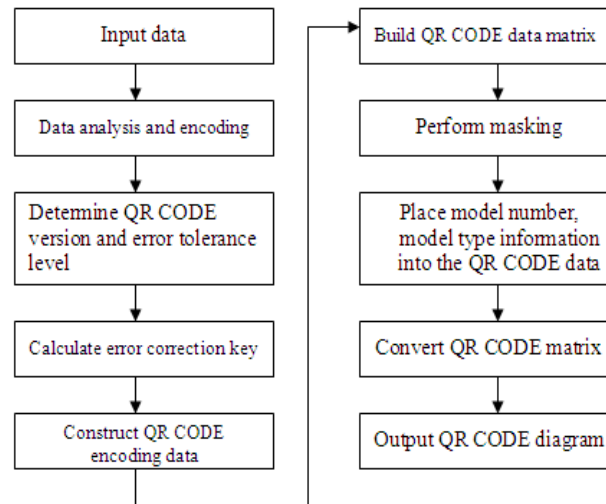


Fig. 2 QR code encoding flowchart

2.2. Decoding the QR code

The QR code decoding includes determining the region of the QR code up to obtaining the encoded character string. Fig. 3 shows the decoding process of the standard QR code decoding.

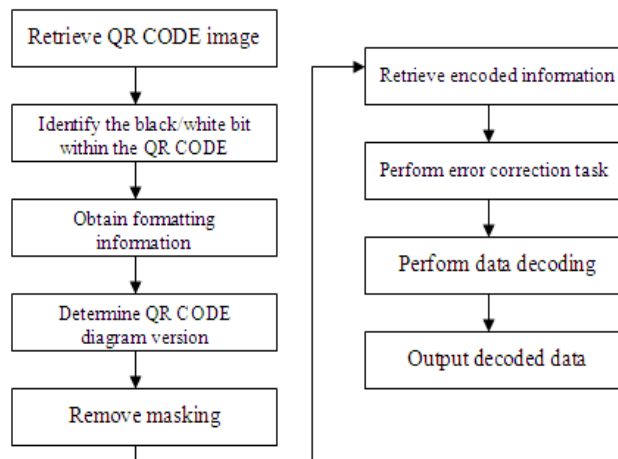


Fig. 3 QR code decoding flowchart

2.3. Pillbox filter [14][15]

The Pillbox filter is used to simulate the out-of-focus blurred algorithm. The definition of the Pillbox filter is shown in equation (1).

$$h(x,y)=\begin{cases} 0 & \sqrt{x^2+y^2} > R \\ 1/(\pi R^2) & \sqrt{x^2+y^2} \leq R \end{cases} \quad (1)$$

Where R represents the radius for the blurred radius. Both x and y are representative of target position. Fig. 4 shows the diffusion function diagram for the $R=1$.

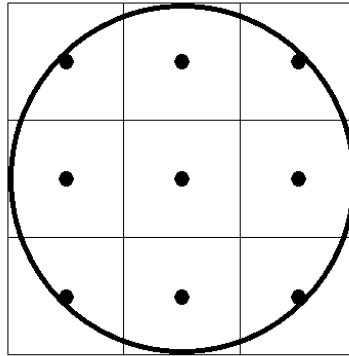


Fig. 4 The diffusion function diagram for the Pillbox filter radius $R=1$

3. Experimental Structure

To investigate the blurriness of QR code images, experimentation using the pillbox filter is conducted using a QR Code image without error. QR code blurry situations caused by distances or the out-of-focus effect are simulated and captured. The influences of the degree of blurriness and recognition are also investigated. The blurry QR codes are reconstructed to generate a clear QR code. The experimental procedures are shown in Fig. 5.

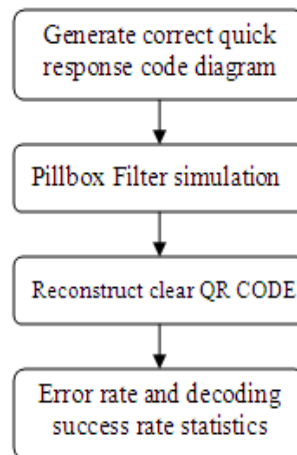


Fig. 5 Experimental structure

Fully correct sets of the QR code are generated, and the decoding is verified by the third-party software to confirm if the generated QR code is correct and can be decoded by other QR code software. Encoder processes are shown in Fig. 6.

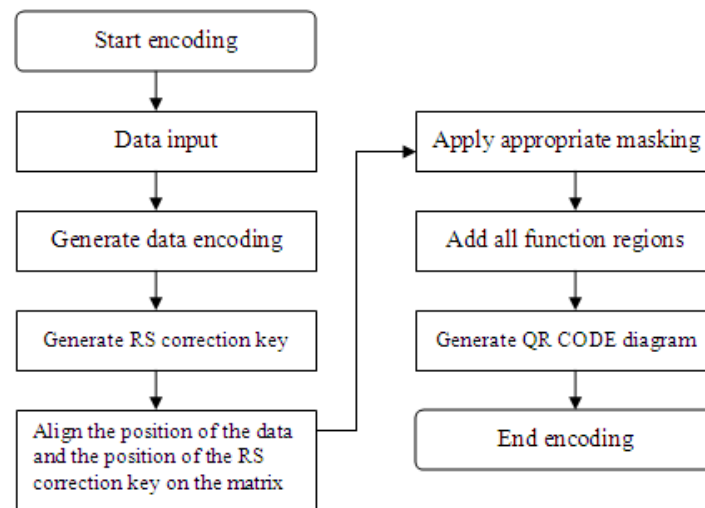


Fig. 6 Encoding structure

The QR code version generated at this stage is 7, and the correction level is H. The length and width of each module is 10 px, as shown in Fig. 7.



Fig. 7 QR code (version: 7, error correction level: H)

The pillbox filter is an algorithm used to simulate out-of-focus blurriness [14]. This experiment uses the pillbox filter to simulate blurry QR code situations caused by the out-of-focus effect to evaluate the value of each QR code module under out-of-focus circumstances. A fully correct and clear QR code is used to create nine sets of QR code images with different degrees of blurriness. The corresponding out-of-focus ratios are 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90%. The “out-of-focus ratio” in this experiment refers to the ratio of the length of the radius of the pillbox filter to the length of a single boundary of an individual QR code module, which denotes the degree of blurriness. When using a QR code bit single boundary length of 10 px and a pillbox filter radius of 5 px to perform the blurring, the out-of-focus ratio is 50%.

Four reconstruction methods are used as follows: average reconstruction, center-point reconstruction, adjacent pixel reference, and adjacent pixel–center-point reference. The module size of the QR code is 10px × 10px, as shown in Fig. 8. Before performing the reconstruction, the pixels within the boundaries of the module are first converted to grayscale for the evaluation for reconstruction, as shown in Table 2.

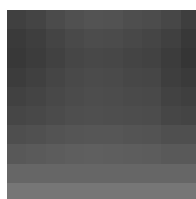


Fig. 8 The module size of the QR code, 10px × 10px

Table 2 Single bit (Module) grayscale 10px×10px

63	71	76	79	80	80	79	76	71	63
56	63	68	71	72	72	71	68	63	56
55	61	66	69	70	70	69	66	61	55
57	63	67	70	72	72	70	67	63	57
62	66	71	74	75	75	74	71	66	62
69	72	76	79	80	80	79	76	72	69
78	80	83	85	86	86	85	83	80	78
89	90	92	93	93	93	93	92	90	89
102	102	103	103	103	103	103	103	102	102
118	118	118	118	118	118	118	118	118	118

In the average reconstruction method, the average grayscale value for each corresponding boundary of the QR code module in the diagram is obtained. The grayscale value of 127 is set as the threshold. A value greater than 127 is defined as 0-bit, and a value less than or equal to 127 is defined as 1-bit. For example, when the average grayscale value of 80.9 is evaluated as 1-bit because it is less than 127 as shown in Table 2.

In the center-point reconstruction method, the grayscale value of the pixel at the center point for each corresponding boundary of the QR code module in the diagram is obtained. The grayscale value of 127 is set as the threshold. A value greater than 127 is defined as 0-bit, and a value less than or equal to 127 is defined as 1-bit. For example, the center-point grayscale value of 75 is evaluated as 1-bit because it is less than 127 as shown in Table 2.

In the adjacent pixels reference method, the average grayscale value for each corresponding boundary of the QR code module in the diagram is obtained. Different grayscale values are set as thresholds. A value greater than 170 is defined as 0-bit, and a value less than or equal to 80 is defined as 1-bit. Codes with these apparent characteristics are processed first. For codes with grayscale values between 80 to 170, the change trend of the eight boundaries of the QR code bit (Module) (top, bottom, left, right, top left, top right, bottom left, and bottom right) in the diagram is evaluated which are. If the grayscale value from the interior toward the exterior of the boundary shows signs of increasing, then the bit is defined as a 1-bit inclination. If four or more boundaries indicate 1-bit inclinations, then the bit is evaluated as 1-bit. If less than four boundaries indicate 1-bit inclinations, then the bit is evaluated as 0-bit. As shown in the Table 2, the average grayscale value is 80.9, which is not within the apparent characteristics of boundary. Hence, the change trend of the eight -boundaries should be evaluated. Four 1-bit inclinations are observed in the diagram. The result of the adjacent pixel reference method is 1-bit.

The adjacent pixels–center-point reference method is a minor modification of the adjacent pixel reference method. First, the average grayscale value for each corresponding boundary of the QR code bit (module) in the diagram is obtained. Different grayscale values are set as thresholds. A value greater than 170 is defined as 0-bit, and a value less than or equal to 80 is defined as 1-bit. Codes with these apparent characteristics are processed first. For codes with grayscale values between 80 to 170, the change trend of the eight boundaries of the QR code bit (module) (top, bottom, left, right, top left, top right, bottom left, and bottom right) in the diagram is evaluated. If the grayscale value from the interior toward the exterior of the boundary shows signs of increasing, the bit is defined as a 1-bit inclination. If six or more boundaries show 1-bit inclinations, the bit is evaluated as 1-bit. If only two or less boundaries show 1-bit inclination, the bit is evaluated as 0-bit. If three to five boundaries exhibit 1-bit inclinations, the center-point reconstruction method is used to evaluate the bit value. As shown in the Table 2, the average grayscale value is 80.9, which is not within the apparent characteristics boundary. Therefore, the change trend of the eight boundaries is evaluated. Four 1-bit inclinations are observed in the diagram, which is within the range of 3 to 5. The result of the center-point reconstruction method is 1-bit.

3.1. Assessing the advantages and disadvantages of the reconstruction methods

The experimentation shows that the adjacent pixel center-point reference method, which is a consolidation of the other three methods (average reconstruction, center-point reconstruction, and adjacent pixel reference methods), is the best reconstruction method. Below is an assessment of the advantages and disadvantages of the three reconstruction methods.

Although the average reconstruction method shows the highest percentage of errors after reconstruction, this reconstruction method can still be used for initial evaluation of the more apparent 1- or 0-bits of the out-of-focus QR code.

In the center-point reconstruction method, the decoding success rate is higher than that of the more adjacent pixel reference method when reconstructing a QR code with blurriness ratio of 80%. However, when the blurriness ratio is higher than 80%, the reconstruction error rapidly increases.

The adjacent pixels reference method enhances the reconstruction ability of the less apparent 1- or 0-bit characteristics during the average reconstruction method of a blurry QR code image. Therefore, for less apparent characteristics, this method is more suitable for the evaluation of the trend changes of the eight boundaries, thereby improving the accuracy of the reconstruction.

The adjacent pixels center-point reference method is comparable to the center-point reconstruction method in terms of accuracy. The locations of the errors during reconstruction are almost entirely different between the center-point reconstruction method and the adjacent pixel reference method. The combination of these two reconstruction methods is the adjacent pixel–center-point reference method.

The relationship of the four reconstruction methods is shown as Fig. 9.

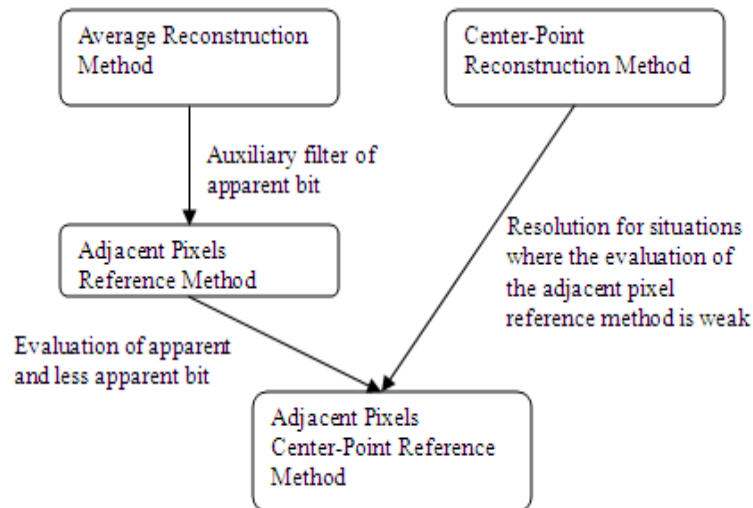


Fig. 9 Relationship among the four reconstruction methods

4. Experiment Results and Analysis

A set of 10%~90% out-of-focus QR code pictures produce using a correct and clear QR code picture. The Pillbox filter algorithm is used here. The final 9 level blurriness ratio of QR code pictures are shown in Fig. 10 to Fig. 18.



Fig. 10 Blurriness ratio of 10% QR



Fig. 11 Blurriness ratio of 20% QR



Fig. 12 Blurriness ratio of 30% QR



Fig. 13 Blurriness ratio of 40% QR



Fig. 14 Blurriness ratio of 50% QR



Fig. 15 Blurriness ratio of 60% QR



Fig. 16 Blurriness ratio of 70% QR



Fig. 17 Blurriness ratio of 80% QR



Fig. 18 Blurriness ratio of 90% QR

The purpose of this paper enhance QR CODE identification rate comparing the four reconstruction methods when the QR code is out-of-focus and blur. The four methods are the average reconstruction method, the center-point reconstruction method, the adjacent pixels reference method, and the adjacent pixels–center-point reference method. Among these methods, the adjacent pixels–center-point reference method is better than others. Table3 to Table 5 are shown the reconstruction effectiveness for 3 different blurriness ratios.

Table 3 Reconstruction effectiveness for blurriness ratio of 70%

	The average reconstruction method	The center-point reconstruction method	The adjacent pixels reference method	The adjacent pixels – center-point reference method
Experimental pictures	300pictures	300pictures	300pictures	300pictures
Average Codeword error rate for each QR code picture	4.05%	0.00%	0.00%	0.00%
Decoding success rate	100.00%	100.00%	100.00%	100.00%

Table 4 Reconstruction effectiveness for blurriness ratio of 80%

	The average reconstruction method	The center-point reconstruction method	The adjacent pixels reference method	The adjacent pixels – center-point reference method
Experimental pictures	300pictures	300pictures	300pictures	300pictures
Average Codeword error rate for each QR code picture	39.77%	7.39%	4.76%	0.00%
Decoding success rate	5.33%	100.00%	100.00%	100.00%

Table 5 Reconstruction effectiveness for blurriness ratio of 90%

	The average reconstruction method	The center-point reconstruction method	The adjacent pixels reference method	The adjacent pixels – center-point reference method
Experimental pictures	300pictures	300pictures	300pictures	300pictures
Average Codeword error rate for each QR code picture	47.04%	36.41%	65.14%	28.56%
Decoding success rate	0.00%	1.00%	0.00%	33.33%

Also, the comparison of all reconstruction decoding success rate is shown in Table 6.

Table 6 Comparison of all reconstruction decoding success rate

Blurriness ratio Methods	10%~60%	70%	80%	90%
The average reconstruction method	100%	100%	5.33%	0%
The center-point reconstruction method	100%	100%	100%	0.01%
The adjacent pixels reference method	100%	100%	98.33	0%
The adjacent pixels – center-point reference method	100%	100%	100%	33%

The conclusions on the blurriness ratios and effectiveness of the reconstruction methods are as follows:

(i) Effectiveness of the different blurriness ratios

- (a) Images with ratios under 60% can be fully reconstructed into correct QR code diagrams.
- (b) The number of modules cannot be reconstructed increases with the increase in blurriness ratio.
- (c) After reconstruction, the decoding success rate decreases with the increase in blurriness ratio.

(ii) Effectiveness of the different reconstruction methods

- (a) The average reconstruction method is the most ineffective among the four methods and is only suitable for obtaining apparent characteristics.
- (b) The result of the center-point reconstruction method is satisfactory.
- (c) The result of the adjacent pixels reference method is also satisfactory.
- (d) The adjacent pixels–center-point reference method produces the best result.

5. Conclusions

When using an image-capturing device to obtain the QR code, many factors generally affect the degradation of image quality, such as blurriness caused by the trembling of the hands, severe distortion caused by the angle of shot, and loss of authenticity due to the different environments. Examples of these include QR codes that are added to the external packaging of the product, which suffer from various distortions caused by the packaging material. The image restorations for these images are being studied by other researchers.

This paper focuses on out-of-focus QR codes and aims to find the best reconstruction method, which may be used as a reference for future research on the quality of QR code images.

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